EFFECT OF SIDE IMPACT PROTECTION IN REDUCING INJURIES

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ABSTRACT

The aim of this study was to identify risk factors in side impact. In particular risk factors such as kerb weight of striking/struck passenger car, age, gender, the presence of a front-seat occupant and side airbags influence the injury outcome. The Swedish database STRADA was used to analyze and identify risk factors in side impact crashes. All near-side front seat occupants in car-to-car side impacts reported by the police from year 2003 to 2009 were included (n=3360). The severity classification made by the police was used to compare the injury risk. Pair comparison technique was used to study the relative risk between the driver in the striking car and the near-side occupant in the struck car. The higher kerb weight of the striking passenger car, the higher risk of being sever injured in the struck passenger car. The opposite relation was found regarding the kerb weight of struck passenger car. Being senior or having a passenger beside in a side impact means a higher risk of sustaining serious injuries. Current side airbag systems, such as torso bags with or without head curtains, reduce the injury risk in side impact for near-side occupants.

INTRODUCTION

Side impact crashes stands for higher risk for the occupants than front and rear collisions. A driver involved in a side impact has twice as high fatality risk as driver involved in frontal impacts (Farmer et al., 1997). A typical side impact crash occurs at relatively low speed. However, the sides of a passenger car have a limited ability to absorb energy in cashes and therefore side impact crashes are already critical at relatively low change of velocity (delta-V). The fatality risk rapidly increase at delta V 40km/h and above (Sunnevång et al., 2009). There are many factors that affect the risk of sustaining injuries in a side impact crash. As in all crash situations it is a balance between crash severity, vehicle factors as well as human injury tolerance. Farmer et al (1997) have pointed out that it is favorable to be an occupant of a heavier vehicle than a occupant in a light weighted vehicle in a side impact. No influence of the striking vehicle's kurb weight was found. Furthermore, occupants in passenger cars are more likely to sustain severe injuries when the striking vehicle is a pickup truck or sport utility vehicle (SUV) than in a car-to-car crash.

Near-side occupants are at higher risk than far-side occupants and account for more than 70 percent of all side impact injuries (Laberge-Nadeau et al., 2009). The risk of severe or fatal injuries is more than twice as high for a near-side occupant than for a far-side. Recently, occupant-to-occupant interaction has been identified as a risk factor. Newland et al (2008) have shown that a driver with a front seat passenger present has a higher risk than a driver without a passenger. It is known from previous studies that both age and gender influence the risk of being fatally injured in a car crash (Bedard et al., 2002). In particular, age and fatality risk are strongly correlated with each other (Braver and Trempel, 2004, Augenstein et al., 2005). In side impact crashes senior drivers are more than three times as likely as non-senior to be severely injured. Sunnevång et al (2009) have shown that senior drivers are killed at lower crash severity than non-senior in side impact. Furthermore, it is well-known that senior driver are overrepresented in intersection crashes (Braver and Trempel, 2004).

Since sides of passenger car have a limited ability to absorb energy in cashes, car manufactures have worked hard to introduce different side impact protection systems. It has been both enforced structures in the doors and B-pillars, but also involving the mid section of the car, such as the Volvo SIPS (Jakobsson et al., 2010). But to date most cars are fitted with side airbags of different kinds. Side airbags were introduced on the market around 1994 and today they are more or less standard among new cars. The side airbag's performance has improved from just protecting the torso to also provide head protection. The benefits of the systems have been proved in crash tests as well as analysis of real-life data. In general cars have been safer during the last 20 years (Kullgren et al., 2009, Farmer and Lund, 2006). However, the improvements in vehicle design differ depending on crash type. A study made by IIHS shows that between 1980 and 2000, the overall car driver death rate in cars 1-3 years old decreased by almost 50% in the United States (Laberge-Nadeau et al., 2009). The improvement for frontal crashes was higher than for side impact crashes (52% compared to 24%). However, Volvo has proved that improvement of the side impact protection has resulted in an overall injury reduction of more than 70 percent (Jakobsson et al., 2010). This is an effect of both structural changes as well as introduction of new systems as torso airbags and head protection curtains. The structural changes have not been studied separately. Recent studies in the USA have also shown that side airbags, protecting head and chest, are saving lives in side impacts. Side airbags reduce the risk of fatal injury by up to 37 percent (McCartt and Kyrychenko, 2007). However, Teoh and Lund (2011) recently show that fatality within the group of cars fitted with side airbag differ. A significant lower fatality rate was found for drivers of cars that preformed good in IIHS side impact crash test than for drivers of cars that performed poorly.

The present paper aims to analyze different risk factors in side impact crashes. In particular risk factors such as kerb weight of striking/struck passenger car, age, gender, the presence of a front-seat occupant and of side airbags influence the injury outcome.

METHOD AND MATERIAL

The Swedish database STRADA (Swedish Traffic Accident Data Acquisition) include police-reported crashes was used to study the different risk factors in side impacts. All near-side front seat occupants in side impacts reported by the police from year 2003 to 2009 were included, in total 3360 crashes. Only car-to-car crashes with front-seat occupants 18 years old and above were selected as well as car manufactured in 1997 or later. The side impacts were selected by using the deformation classification made by the police (for driver vehicular damage on the left aspect of the car and for passenger vehicular damage on the right aspect of the car). Multiple event crashes were excluded. Furthermore, the identification number that Swedish Transport Administration assigns each car model was used to identify if the included cars were fitted with side airbag protection or not.

The dataset was divided into different groups to study effectiveness of side impact protection, influence of age, presence of another front-seat occupant, posted speed limit and kerb weight of the striking and struck passenger car. To study the influence of age the dataset was divided into two subgroups; senior drivers (age 60 years and above, n= 655) and non-senior drivers (n= 2 711). In 760 cases a front seat passenger accompanied the driver. The injury rate in these cases was compared with the rest of the crashes to study if the presence of a front-seat occupant influences the risk of being injured. Furthermore, the dataset was divided into two groups; crashes on roads with a posted speed limit under 70km/h and roads with a posted speed limit of 70km/h or above. The severity classification made by the police (non-injured, minor, serious, and fatal) was used to compare the compare the injury outcome between the different subgroups. Fisher's exact test was used to analyze whether there was a difference in proportions of injuries between the categories (age, presence of a front-seat occupant, posted speed limit). In all analyses 95 percent confidence intervals (CIs) were used, and p-values from Fisher's exact tests were calculated using PASW 18.0 (http://www.spss.com).

To study effectiveness of side impact protection and influence of kerb weight on injury risk car-to-car crashes with known injury severity in both the striking and struck passenger car was selected, in total 1767 crashes. Pair comparison technique was used to study the relative risk between the driver in the striking passenger car and the near-side occupant in the struck passenger car (Hägg et al., 1992, Evans, 1991). Using a pair comparison makes it possible to control for crash severity. According to Evans (1986), the relative injury risk was calculated with paired comparisons. The relation of injuries for struck car and striking car is given in table 1. To study effectiveness of side airbags the data was divided into two groups; cars with (n=1263) and cars without (n=435) side airbags, table 2. Both torso bags with or without head curtains were included in the group with side airbags. Car models with optional status of side airbag were included in the group without side airbag. Seventy-nine cases were excluded since it was not possible to identify if car was fitted with airbag or not. In 1909 crashes data about kurb weight as well as the injury outcome in both the striking and struck passenger car were known.

Table 1. Categorization of crashes to be used in the paired comparisons

		Drivers in the striking car		Total
		drivers injured	drivers not injured	
Near-side occupant in the struck car	Near-side occupant injured	x_1	x_2	$x_1 + x_2$
	Near-side occupant not injured	x_3	x_4	
Total		$x_1 + x_3$		

x_1 = number of crashes with injured drivers/occupants in both cars
x_2 = number of crashes with injured drivers/occupants in the struck car and not in the striking car
x_3= number of crashes with injured drivers in the striking car and not in the struck car
x_4= number of crashes with no injured drivers/occupants in both cars

The risk ratio was calculated according to Eq. 1.

$$R = p_1 / p_2 = (x_1 + x_2) / (x_1 + x_3) \quad (1).$$

p_1 = injury risk in struck cars, p_2 = injury risk in striking cars

Risk ratio was calculated for the two groups; cars with and cars without side airbags. Confidence intervals were calculated using the Eq. 2.

$$V(R) = (p_1^*/ p_2^*)^x((1-p_1^*)/(x_1+x_2) + (1- p_2^*)/(x_1+x_3)) \quad (2).$$

where p_1^*/ p_2^* is estimated by R, while p_1^* and p_2^* must be chosen arbitrarily (Hägg et al., 1992). In this study p_2^* was chosen as 0.7 and $p_1^*=R^* p_2^*$.

Table 2. Distribution of age, mean kerb weight for striking and struck passenger car

Mean	Without side airbag (n=435)	With side airbag (n=1263)
Age	45	46
kerb weight, struck car (kg)	1370	1490
kerb weight, striking car (kg)	1290	1390
mass ratio (μ)	1,06	1,07

Influence of car mass difference on injury outcome

The relation between the number of crashes with injured drivers/occupants in both passenger cars and the number of crashes with injured near-side occupant in the studied passenger car is a measure of the injury risk in the other passenger cars. The injury risk in car 2, p_2, can therefore be estimated as the relation $x_1/ (x_1 + x_2)$. Assuming that for every car 1 studied, its colliding partners, car 2, would be of equal design, mass and structure, p_2 would be identical in every case. Similarly the injury risk in car 1, p_1, can be estimated by the relation $x_1/ (x_1 + x_3)$.

The difference in the estimated p_2 and p_1 will differ depending on the influence of three factors; mass, aggressivity related to the structure and crash severity. By selecting passenger cars of different mass categories and where the structural aggressivity and crash severity could be regarded as equal it is possible to calculate the mass factor.

The cars were categorized in 200 kg intervals and the estimates of p_2 and p_1 were calculated for each comparison of mass categories. Both the kerb weight for the striking and the struck passenger car was divided in to the following categories: <1250,

≥1250 to <1450, ≥1450 to <1650 and ≥1650 kg, table 3. The correlation between mass ratio and the estimates of p_2 and p_1 was used to study the influence of mass on injury risk in both striking and struck passenger cars. Mass factors were calculated to be used to adjust for the influence on mass on injury risk in the striking passenger car in the comparison between categories. The adjustment has to be made in order to compare the car groups studied to striking cars with identical average masses. The adjustment was made by applying a power function curve fit and reduce the power with a factor relating to half of the total influence of mass on relative injury risk, equal to the influence on the striking car group.

Tabel 3. Kurb weight distribution for striking and struck passenger car

Kurb weight (kg)	Struck car (n)	Striking car (n)
<1250	363	517
1250 - <1450	473	525
1450 - <1650	565	456
>1650	366	269
Total	1767	1767

RESULTS

The influence of mass differences on injury risk in striking and struck car groups seems to be of similar order, Fig 1. The reduction in risk for the struck car, p_1, at increased mass ratio is similar as the increase in risk for the striking car, p_2.

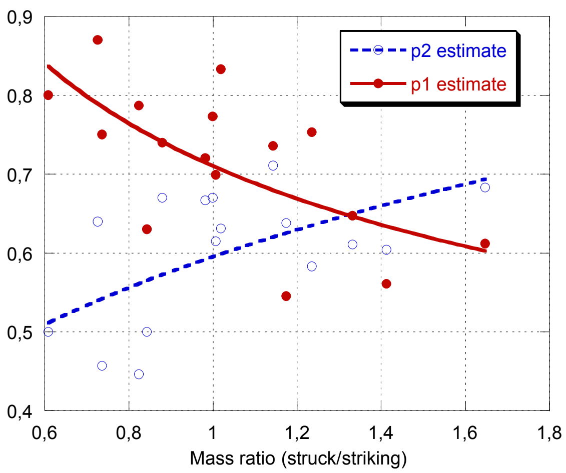

Figure 1. Relation between estimates of injury risk in the struck, p1, and striking cars, p2, at various mass ratios.

Higher kerb weight of the striking passenger car increased the relative risk of being seriously injured in the struck passenger car. The opposite relation was found with increasing kerb weight of the struck passenger car. Furthermore, a higher the mass ratio (μ) was favorable for the struck passenger car. Figure 2 and 3 shows the relation between mass ratio and relative risk of all injury and serious injury and fatal respectively for the mass ratios studied. The figure also shows the calculated mass factors for the two injury categories studied. According to the equations found the measured relative risk should be reduced at low mass ratios and increased at high mass ratios. For all injuries the mass factor is 1.163 μ ^(-0.336), and for fatal and serious it is 1.013 μ ^(-1.314).

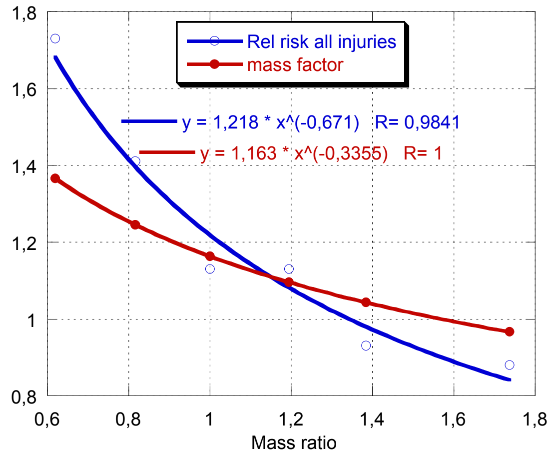

Figure 2. Correlation between relative risk for all injuries and mass ratio between struck and striking car, and calculated mass factor to be used for adjustment of measured injury risk.

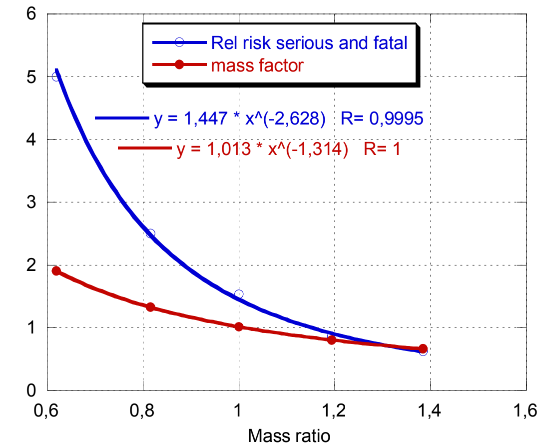

Figure 3. Correlation between relative risk for fatal and serious injuries and mass ratio between struck and striking car, and calculated mass factor to be used for adjustment of measured injury risk.

The risk of sustaining injury in a side impact was lower in a passenger car fitted with side airbags (Risk ratio 1.13, CI 1.078-1.182, Appendix table 1 and 3), protecting head and chest, than in a car without these systems (Risk ratio 1.28, CI 1.194-1.366, Appendix table 2 and 4). The relative injury risk in car-to-car crashes, calculated with paired comparisons, indicates a risk reduction of almost 30 percent between the two groups: passenger car fitted with side airbags, protecting head and chest, and car without these systems. Also far-side occupants were found to have a positive effect of the side airbags.

The age influences the injury risk. Senior car occupants (age 60 years and above) had a significantly higher risk of sustaining serious injuries (26% higher risk in a car-to-car crash). Furthermore, the presence of a front-seat occupant influences the risk of being seriously injured irrespective of side protection system. An occupant besides you in a side impact means up to 45 percent higher risk of being injured. A significantly higher proportion of serious injuries occurred on roads with a speed limit of 70 km/h or above. The exposure for gender was similar except from that female occupants were more likely to sustain minor injuries.

DISCUSSION

The risk of being injured in a side impact is influenced by so many risk factors that it is impossible to identify the importance of just a single one. The present study shows that the absence of side airbags, the occupant's age, the presence of a front-seat occupant and kerb weight of both the striking and struck passenger car all influence the risk of being injured in a side impact crashes. Simultaneously as car manufacturers installed side airbag they also introduced structural innovations that in general improved the side impact protection. These improvements also influenced the kerb weight of the passenger cars. The mean weight of passenger cars with side airbags was 120 kg more than a passenger car without side impact protection. The result from the present study shows that it is favorable in a car-to-car crash if the struck passenger car was heavier than the striking. Furthermore, the fact that the far-side occupant have a positive effect of the side airbags indicate that passenger cars fitted with side airbags in general have a higher safety level.

Near-side occupants are at higher risk than far-side occupants and account for more than 70 percent of all side impact injuries. It is therefore natural that the car manufactures have had focus on side protection systems for the near-side occupant. Result from the present study shows that an occupant beside in a side impact means up to 45 percent higher risk of being injured. Newland et al (2008) have shown from both real-life data and crash tests that occupant-to-occupant interaction in side impact crashes can cause injuries. They found that the relative risk for sustaining severe injuries (MAIS3+) was 8% higher for the near-side occupant in cases where a belted far-side was present than without a far-side occupant. An even higher risk (30%) was found in cases with an unbelted far-side occupant beside the driver. These results together point out that there is a need to develop some type of protection system that minimize the occupant-to-occupant interaction.

Senior drivers have particularly higher risk than non-senior drivers. These findings represent both crashes with and without airbag. Furthermore, it was expected that senior drivers would have a higher injury risk than non-seniors. Previous studies have shown that senior drivers are more likely to be severely injured (Sunnevång et al., 2009, Braver and Trempel, 2004, Farmer et al., 1997). However, little have been done to invent side impact protections that comply with different needs for non-senior and senior occupants.

It is known from previously studies that the effectiveness of side airbag is high in fatal crashes (Braver and Kyrychenko, 2004, McCartt and Kyrychenko, 2007). This study indicates that the side airbag also reduce the number of injured occupants in car-to-car crashes. However, it was not possible to see any reduction of sever injures. The Swedish national database included very few seriously injured occupants in side-impact crashes during the 2003-2009 and therefore it was not possible to estimate the true effectiveness of the side airbag. Side airbag became widely available in car models manufactured after 1998 and in recent years there has been a growing trend among car manufactures to offer side airbag protection as standard. It is therefore a higher proportion of cars fitted with side airbags as standard included in the present study (74% of the total number). Data from USA shows that 79% of 2006 passenger car models had side airbag as standard (45%) or optional (34%) equipment (McCartt and Kyrychenko, 2007). The Swedish national database included very few numbers of crashes involved cars manufactured in 1997 or later without side airbags. One possible method to increase the number would have been to extend the model year for the included cases. However, the authors did not change the inclusion criteria. The reason for this is that car safety have improved a lot during the last 20 years (Kullgren et al., 2009, Farmer and Lund, 2006). By including cars manufactured before 1997 would rather reflect other differences.

Teoh and Lund (2011) recently showed that fatality risk within the group of cars fitted with side airbag differ. A significant lower fatality rate was found for drivers of cars that preformed good in IIHS side impact crash test than for drivers of cars that performed poorly. The result in this study might have been influenced of the fact that different airbag design effect the fatality risk differently in side impact crashes. It is likely to believe that cars performing well in IIHS side impact crash test would have had a lower injury risk than the total injury reduction for side airbag system. In the present study different types of airbag systems including torso-only, torso–head (combination bag), torso–curtain or, inflatable tubular curtain were all included in the same group. Out of 1263 crashes where the car was fitted with side airbag, a majority were torso-curtain side airbags (69%). Due to the low number of crashes with serious injuries it was not possible to study the side airbag effectiveness for torso bags and head curtains separately.

Assuming a positive correlation between posted speed limit and impact speed it is natural that a higher proportion of serious injuries occurred on roads with a speed limit of 70km/h or above. Studies have shown that the posted speed limit strongly influences the impact speed and increases the risk of injury (Ydenius, 2009, Stigson, 2009). To minimize the injury outcome in side impact crashes it is therefore recommended to limit the posted speed limit and even better redesign the infrastructure. Road design solutions such as roundabouts have been shown to dramatically reduce the number of crashes resulting in injuries (by up to 80%) at intersections compared with traditional intersection designs (Persaud et al., 2001, De Brabander and Vereeck, 2007).

Limitations

There is a strong correlation between change of velocity and risk of injury (Kullgren, 1998, Gabauer and Gabler, 2006, Gabauer and Gabler, 2008). Using a pair comparison makes it possible to control for crash severity. It is therefore not necessary to have the impact severity in terms of change of velocity (delta-V) or compartment intrusion in each case. To evaluate the effect of a side airbag the injury risk for the driver in the striking car was compared with the risk of serious injuries in the struck car. This comparison was used since it is likely that the driver of the striking passenger car got a lower risk to sustaining sever injuries than the occupant in the struck car.

The study is based on police reported data. The study was therefore limited to analyses based on only injury severity classified by the police. It is known that the severity of crashes assigned by the police at the accident scene, i.e. whether those involved are considered seriously or slightly injured, is mainly based on whether the injured person is expected to be admitted to hospital or not. The classification of injury severity only gives a rough picture of the true severity of the injury (Farmer, 2003). Furthermore, it is a weakness that it is unknown which type of injury the occupant got. The highest risk of serious injury is to the torso and the head and the side airbags are mainly design to reduce thorax and head injuries. It would therefore be more accurate to focus only on injuries to these two body region.

Previous studies have point out that driver of cars with side airbags probably are of higher socio-economic status because these cars are more costly. Travel patterns and driver behaviors sush as speeding, influence of alcohol and seat belt vary systematically by socioeconomic status (Braver, 2003). Thereby drivers of cars with side airbags could have a lower likelihood of being in a serious crash. McCartt A. and Kyrychenko have adjusted for these potentially confounding factors by using frontal and rear end crashes. This has not been taken into consideration in the present study.

CONCLUSION

- The higher kerb weight of the striking passenger car, the higher risk of being seriously or fatally injured in the struck passenger car. The opposite relation was found regarding the kerb weight of struck passenger car.
- Being senior or having an occupant besides you in a side impact means a higher risk of sustaining serious or fatal injuries.
- Current side airbag systems, such as torso bags with or without head curtains, reduce the injury risk in side impact for near-side occupants.

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APPENDIX

Table 1. Risk of sustaining injury in a side impact in a passenger car without side airbag

Without side airbag		Driver in striking car		Total
		injured	not injured	
Occupant in struck car	injured	192	135	327
	not injured	63	35	
Total		255		

Table 2. Risk of sustaining injury in a side impact in a passenger car fitted with side airbags, protecting head and chest

With side airbag		Driver in striking car		Total
		injured	not injured	
Occupant in struck car	injured	556	336	892
	not injured	233	138	
Total		789		

Table 3. Risk of sustaining serious injury in a side impact in a passenger car without side airbag (Serious injuries in the struck car)

Without side airbag		Driver in striking car		Total
		injured	not injured	
Occupant in struck car	Sever injured	29	13	42
	not sever injured	226	157	
Total		255		

Table 4. Risk of sustaining serious injury in a side impact in a passenger car fitted with side airbags, protecting head and chest (Serious injuries in the struck car)

With side airbag		Driver in striking car		Total
		injured	not injured	
Occupant in struck car	Sever injured	72	27	99
	not sever injured	717	447	
Total		789		